N87-16414

NOVEL MEASUREMENT TECHNIQUES (DEVELOPMENT AND ANALYSIS OF SILICON SOLAR CELLS NEAR 20% EFFICIENCY)

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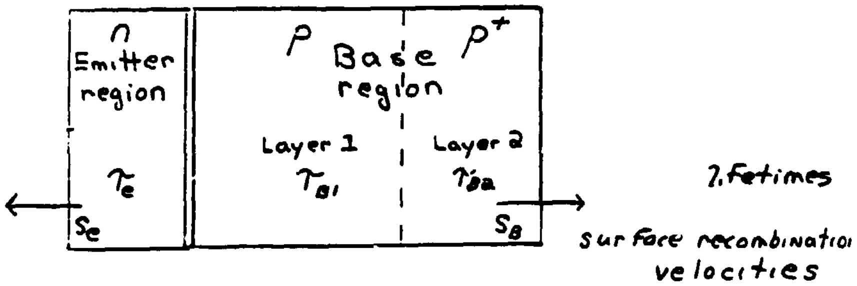
Typical High-Efficiency Device

Traditional lifetime measurement techniques have been directed at extracting a single bulk lifetime from rather simple structures in which nonuniformities, drift fields and surface recombination velocities were ignored.

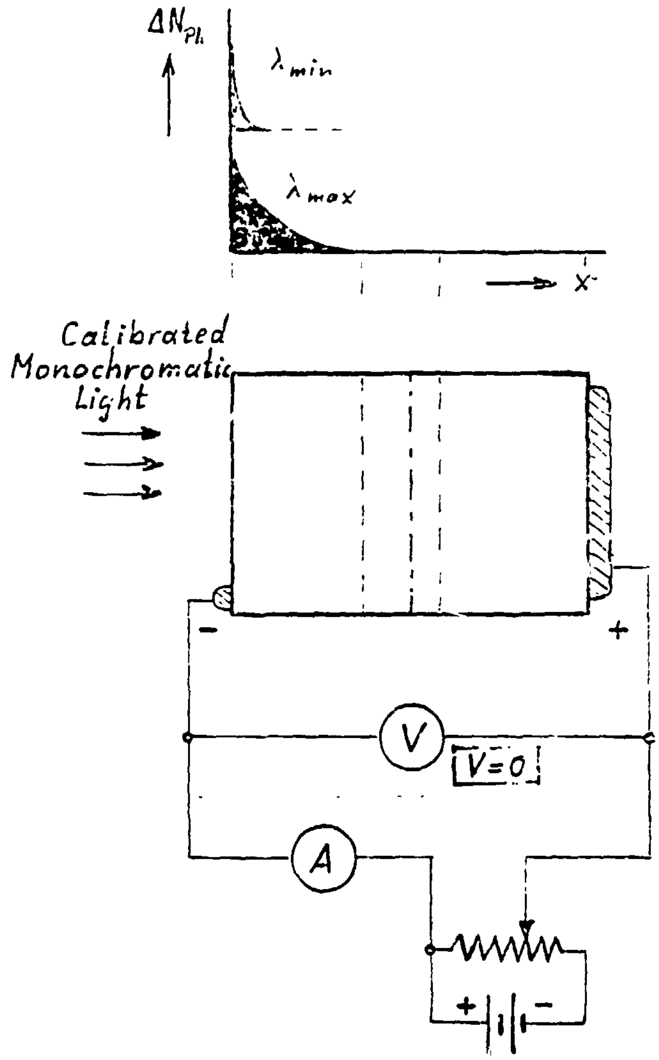


Real devices have multiple unknown recombination and transport parameters

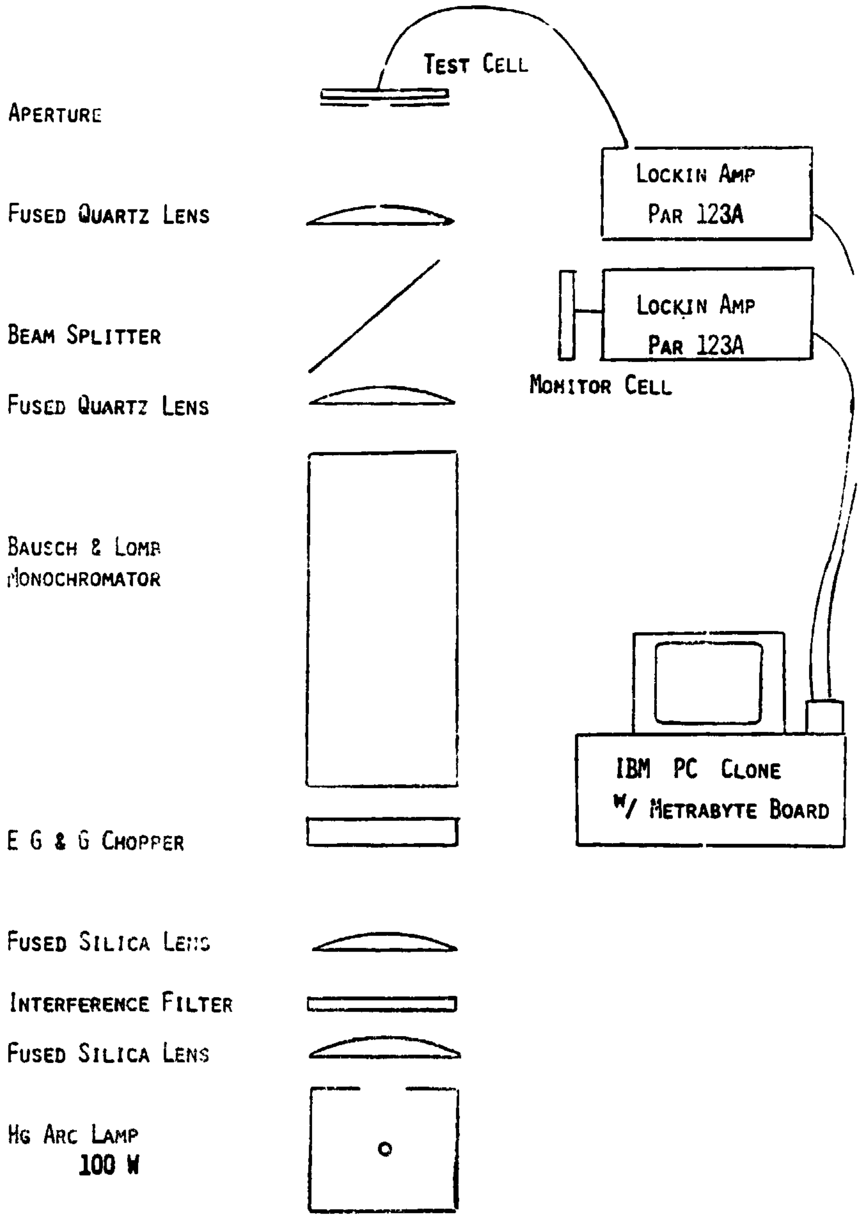
Objectives

1. REFINE, AUTOMATE, AND APPLY ASLBIC METHOD.
2. DEVELOP GENERIC METHOD FOR EVALUATING AVAILABLE METHODS FOR S AND τ DETERMINATION IN COMPLEX DEVICE STRUCTURES (SOLAR CELLS):
   A. ESTABLISH GENERAL THEORY.
   B. APPLY TO DETERMINING RELATIVE ADVANTAGES, LIMITATIONS OF CANDIDATE METHODS.
   C. DERIVE METHODS FOR REDUCING MEASURED DATA FROM THESE METHODS TO MEANINGFUL S, τ VALUES IN RELEVANT PARTS OF COMPLEX DEVICES.
   D. IF POSSIBLE, APPLY INSIGHTS GAINED TO DEVELOPMENT OF MORE SUITABLE METHODS.
3. ESTABLISH TO WHAT EXTENT S AND AN "EFFECTIVE τ " CAN BE DETERMINED IN THE COMMONLY USED "EMITTER" ($x_J \approx 0.2\ \mu$M; $N_{D,S} \approx 10^{19} - 10^{20}$ CM^{-3}).
   (EXAMPLE: FSA - COMMITTEE SOLAR CELL DESIGN)

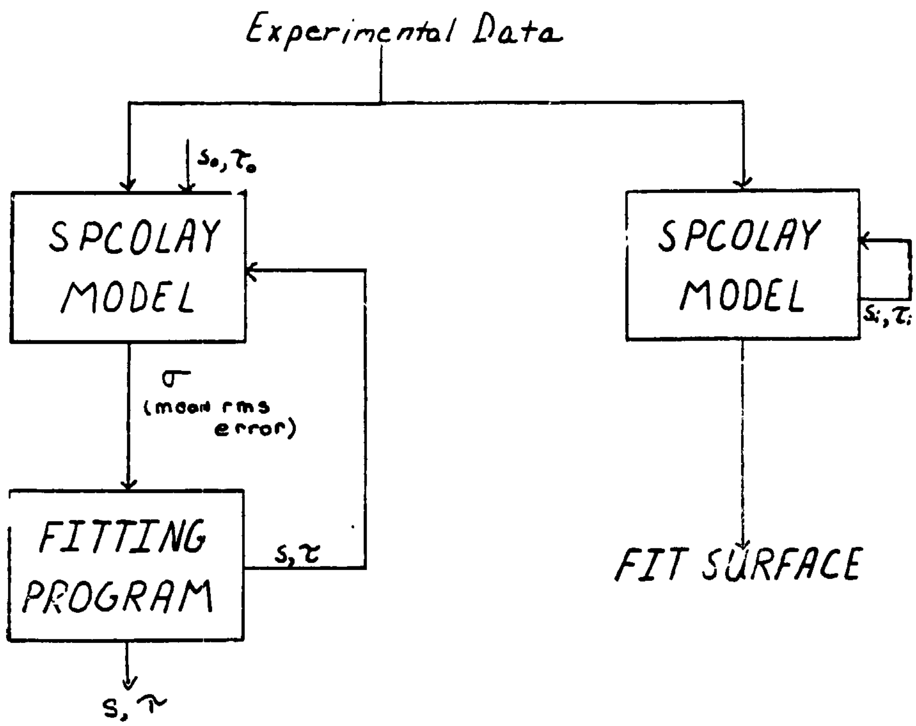
Absolute Spectral Light Beam Induced Current (ASLBIC)



ASLBIC Facility

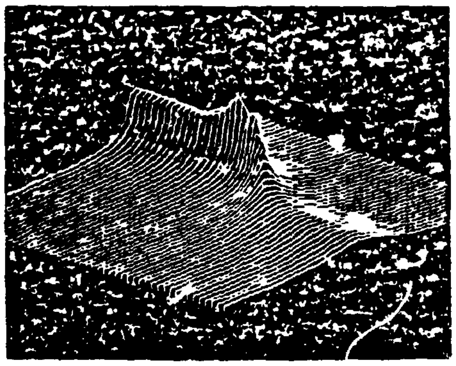


ASLBIC Fitting

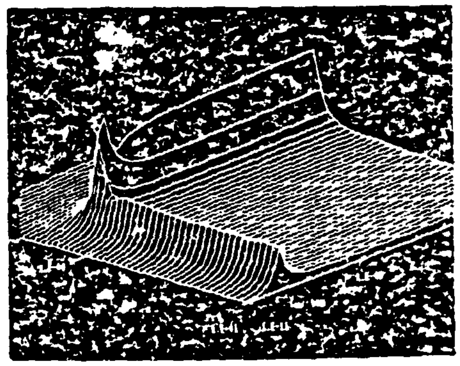


Two Fitting Methods

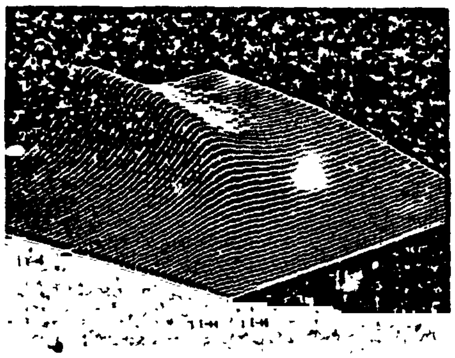
1. *Steepest Descent*
   go down steepest hill
2. *Simplex*
   NEW METHODS
   not intuitive
   works best



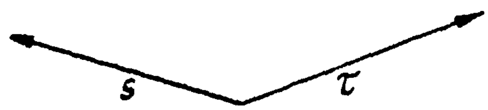
3μm uniform (theor'l)



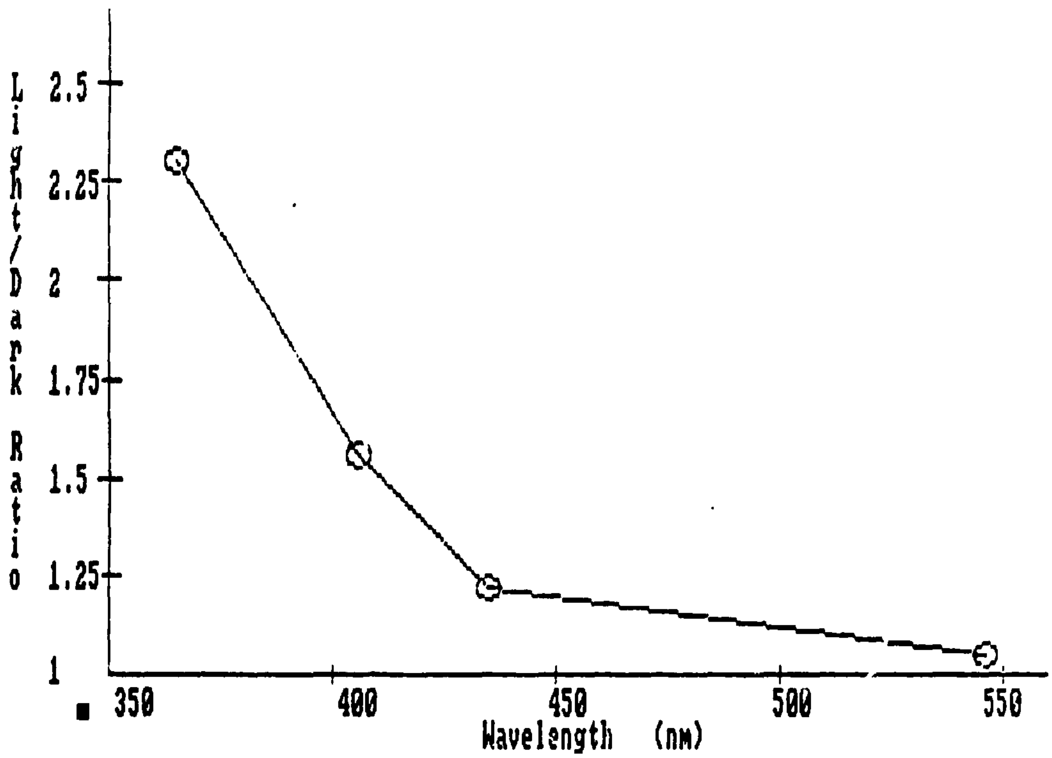
Spire 4400 20B
0.3μm SIMS data → 3 layers
(same τ)



A-3-1-216/100-2-3, 100 μm unif'm.



Effect of Bias Light Versus Wavelength for a-3-1-216/2-1-2



Measurement Types

- *Steady State*

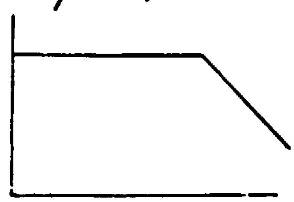
  vs. wavelength
  vs. distance
  vs. voltage

- *Relaxation Constant Measurements*
  - *Decay measurements*

    vs. time

  - *Modulation measurements*

    vs. frequency



$$D\frac{\partial^2 n}{\partial x^2} - \frac{n}{\tau} = \begin{cases} -G_n(x) & \underline{\underline{\text{steady state}}} \quad \left[G_n(x) = N_{ph}\,\alpha\, e^{-\alpha x}\right] & n(x) = A\,e^{\frac{x}{L}} + B e^{-\frac{x}{L}} + C e^{-\alpha x} \\ \frac{\partial n}{\partial t} & \underline{\underline{\text{free decay}}} & n(x,t) = \sum_{i=1}^{\infty} A_i e^{-\left(\frac{1}{\tau}+\lambda_i\right)t}\,\phi_i(x) \\ \frac{\partial n}{\partial t} - G_n(x,t) & \underline{\underline{\text{forced oscillation}}} \quad \left[G_n(x,t) = G(x)e^{j\omega t}\right] & n(x,\omega) = \sum_{i=1}^{\infty} \frac{D_i^2\,\phi_i(x)}{\frac{1}{\tau}+\lambda_i + j\omega} \int_0^d \phi_i(\xi) G_n(\xi)\,d\xi \end{cases}$$

The Meaning of the Constants in Decay Modes

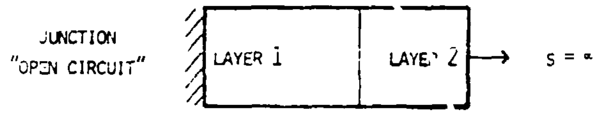
A. $\beta_i = \frac{1}{\tau} + \lambda_i$ ARE THE RELAXATION CONSTANTS OF THE SYSTEM.
THEY ARE OBSERVABLE.

B. $1/\tau$ CHARACTERIZES THE EFFECTIVE MINORITY CARRIER RECOMBINATION RATE
IN THE VOLUME OF THE LAYER AT WHICH THE OBSERVATION IS MADE.
(IF THIS RATE IS UNIFORM IN THE VOLUME, THEN τ IS THE M.C. LIFETIME.)

C. λ_i ARE THE EIGENVALUES WHICH DETERMINE THE DIFFUSIVE DECAY
OF THE M.C. IN THE LAYER UNDER OBSERVATION.
THEY ARE DETERMINED BY:

1. ANY "SINKS" OUTSIDE OF THE LAYER CONSIDERED
   (SUCH AS: SURFACE WITH RECOMBINATION:
   BOUNDARY TO JUNCTION IN NOT-FLAT-BAND CONDITION:
   BULK RECOMBINATION).
2. THE TRANSPORT PROPERTIES OF THE LAYER AND INTERVENING LAYERS.

D. WHICH, AND HOW MANY, OF THE INFINITELY MANY λ_i ARE OF SIGNIFICANCE,
IS DETERMINED BY THE INITIAL EXCESS MINORITY CARRIER DISTRIBUTION
AND THE PROPERTIES OF THE LAYER.



VARIATION CASE	BASELINE CASE: UNIFORM (ONLY 1 LAYER)		DOPING		D		τ		LSA		LSA, BUT LOW τ IN LAYER 2	
LAYER	1	2	1	2	1	2	1	2	1	2	1	2
THICKNESS (μm)	60	40	→									
DOPING (cm^{-3})	5E16	5E16	5E16	2E18	5E16	5E16	→		5E16	2E18	→	
D (cm^2/s)	15.5	15.5	→		15.5	5.95	15.5	15.5	15.5	5.95	→	
τ (μs)	33	33	→				33	2	33	2	33	0.27
$-\beta$:	2.4		21.6		4.8		2.2		25.8		11.2	

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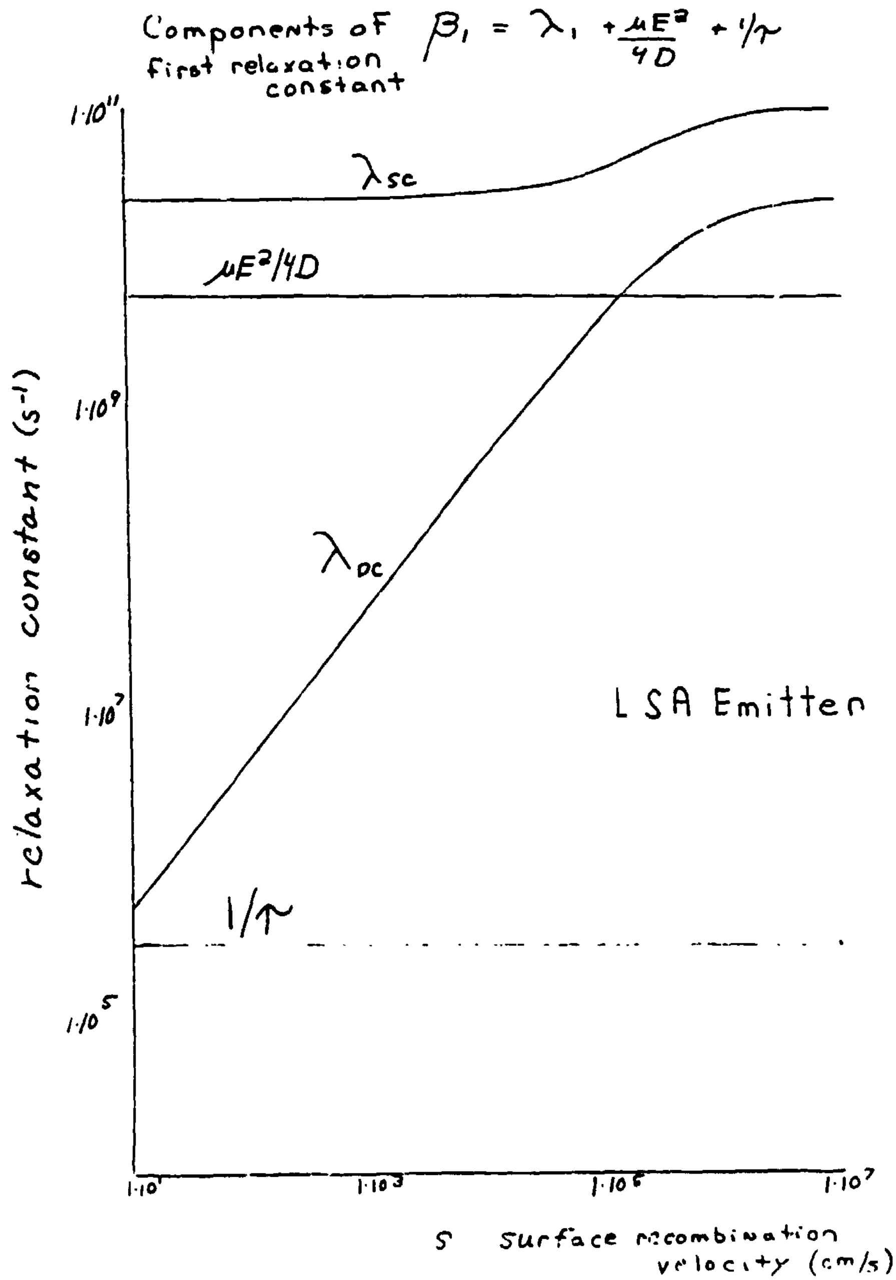
OF POOR QUALITY


Components of first relaxation constant $\beta_1 = \lambda_1 + \frac{\mu E^2}{4D} + 1/\tau$
$1 \cdot 10^{11}$
$1 \cdot 10^{9}$
$1 \cdot 10^{7}$
$1 \cdot 10^{5}$
λ_{sc}
$\mu E^2/4D$
λ_{oc}
$1/\tau$
L SA Emitter
relaxation constant (s^{-1})
$1 \cdot 10^{1}$
$1 \cdot 10^{3}$
$1 \cdot 10^{5}$
$1 \cdot 10^{7}$
S surface recombination velocity (cm/s)